Ingraffea - Rock mechanics

EXHIBIT 9

NORMA FIORENTINO, et al.,	)	3:09-cv-02284
	)	
Plaintiffs,	)	Hon. John E. Jones III
v.	)	
	)	Magistrate Paul C. Carlson
CABOT OIL & GAS	)	
CORPORATION and GAS SEARCH	)	
DRILLING SERVICES CORP.,	)	
	)	
Defendants.	)	

AFFIDAVIT IN OPPOSITION TO DEFENDANTS' MOTIONS FOR SUMMARY JUDGMENT AND
PARTIAL SUPPLEMENTAL EXPERT REPORT

I, Anthony Ingraffea, certify pursuant to the penalty of perjury under 28 U.S.C. 1746, that:

1. My name is Anthony Ingraffea. I am an engineer and rock mechanics scientist. I am also a full and chaired professor of engineering at Cornell University in Ithaca, New York.
2. I submit this affidavit in support and partial rebuttal of defendants' expert report, in support of remaining pro se plaintiffs' litigation claims and in opposition to defendants' motions for summary judgment.
3. In the 1980's I performed some of the original modeling that demonstrated the effects of hydraulic fracturing on shale rock and the mechanism by which it causes pathways for subsurface fluid and gas migration. I have appended to this affidavit an excerpt from my complete curriculum vita documenting that I am widely published, and recognized in my professional community as an authority in this area. Many of the publications in this excerpt were co-authored with industry scientists and engineers.

4. My complete curriculum vita is attached for efficiency in disclosing my complete educational and professional background, and a record of my original scientific and peer-reviewed publications, and awards.

5. I will, however, venture to state that for many years while in academia, I have been retained by the gas and oil industry as a researcher and consultant, during which time I became extremely well versed in petroleum engineering and gas drilling operations, and how they have evolved, or perhaps devolved, depending on which side of the fence you sit, since the mid-twentieth century.

6. At their request, in February 2012, I provided plaintiffs' Napoli Bern Ripka Scholnick, plaintiffs' former attorneys, with what I understood was to be a draft report in connection with providing an expert opinion in this case.

7. While I never heard from anyone at the law firm again concerning the fate of that draft report, I did come to later learn from Nolen Scott Ely that, surprisingly, the draft report was exchanged with the defendants' law firm. This was not my intention, but nonetheless I stand behind the import of its substance, if not its' less than legally perfect form.

8. What I also learned from Mr. Ely is that this Court has ordered that supplemental expert reports were to have been filed by June 3th.

9. My understanding is that Mr. Ely received defendants' expert reports sometime during the week of April 29th. I received them from Mr. Ely within the following week. I alerted Mr. Ely that as wholeheartedly I wished to meet that deadline, it would not be possible, this due to my full teaching schedule, various other

outstanding obligations to the university, supervision of students, speaking engagements and travel plans. And the earliest I could provide a complete supplemental report, particularly since this project had been nascent for over one year, and that I would have to revisit an entire bankers' box full of data, added to that another box of defendants' papers, was not until the end of July.

10. I know that pro se plaintiffs were to have made a request of the Court for me in that regard.

11. Nonetheless, prior to my work for the Napoli law firm, I had never agreed to provide an expert opinion or testimony in any court case involving natural gas migration. What made this case different was the blatancy of the gas company's errors and their connection to the water contamination the folks in Dimock, most pertinently now, the Elys and Huberts, have suffered.

12. I am fully familiar with the pleadings in this case, I have reviewed pertinent data and discovery as well as defendants' expert reports and statements with regard to defendants' denial that their activities have caused migration of natural gas and other materials into the domestic well water supplies of the Ely and Hubert households. I could not disagree more vigorously. The evidence of negligence and causation on the part of the gas company and its drilling operators is, frankly, overwhelming and irrefutable.

13. I have also reviewed the affidavits of the pro se plaintiffs as well as those of Paul Rubin, hydrogeologist, with whose work in the area I am very familiar, and Robert Congdon, Jr., real estate appraiser and minerals valuation expert.

14. I intend to testify at the time of trial of this matter that, to a reasonable degree of engineering certainty, it is more likely than not that: i) drilling operations of the sort engaged in by defendants Cabot Oil & Gas Corporation and Gas Search Drilling Services, Corp., by nature, disrupt rock, gas, and fluids below the earth and create subsurface pathways by which rock debris, natural gas other subsurface fluids will migrate, by virtue of the "hydraulic effect," from the fluid bearing formations to ground water and drinking supplies in the absence of competent casing and cementing of the well by competent well construction and drilling personnel; ii) in the absence of such competence, gas wells have an increased tendency to "fail; iii) multiple Cabot gas wells within the infamous "9-square mile (Carter Road) affected zone" of Dimock did fail, not just according to this expert, but more importantly according to the repeated and documented findings of the Pennsylvania Department of Environmental Protection, due to negligent and faulty construction by Cabot and its operators; iv) among those failed wells were Gesford 3, Gesford 3S, Gesford 9 and others located in the vicinity of the Ely and Hubert households; v) as a result, methane gas together with other unwelcome constituents and fluids were allowed to migrate, as they naturally will, into the aquifer that supplies the well water to the Nolen Scott Ely and Ray Hubert households.

15. History of Current Hydraulic Fracturing.[1]

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[1] (Montgomery and Smith, Hydraulic Fracturing: History of An Enduring Technology, JPT, December 2010; Be Hydraulic Fracturing: The Fuss, The Facts, The Future, JPT, December, 2010)

(i) Historically, natural gas was produced by means of constructing and installing a vertical well into the ground in a natural gas rich "play," thus creating a straw-like pathway for the gas flowing, from the reservoir, under its own natural pressure to be recovered at the surface.

(ii) In the mid twentieth century, engineers first experimented with the technique of stimulating trapped gas out of low permeability rock through a process of injecting a liquid under high pressure into a well. At that time, operators employed vertical well technology and delivered approximately a few thousand gallons of liquid per well under a few thousands of pounds per square inch of pressure. The practice became common in non-shale rock plays, but did not "catch on" in shale plays because it had an unfavorable cost-benefit ratio: too much expense for too little return on investment.

(iii) Although the grant of a patent was issued in 1891, the first horizontal wells were not drilled until 1929 at Texon, Texas. Yet, again, this process did not take hold until the late 1970's and early 1980's when oil prices dropped and the demand for more efficient development costs grew.

(iv) It has only been within the last decade that hydraulic fracturing in shale plays became a feasible financial endeavor, and this by virtue of the confluence of particularly favorable political and commercial factors.

(v) First, the vertical drilling and fracturing was enhanced by a novel methodology developed in about 1997 known as high-volume slick water

hydraulic fracturing combined with horizontal well drilling.[2] The so-called "slick water" combines anywhere between 2 and 9 million of gallons of water per well with additives to prevent corrosion, inhibit bacterial growth, among other things, and to coax the gas out of the shale. Next, clusters of well pads, each with multiple, closely spaced wells are used to blanket the shale play.

(vi) These additives, many of which are known carcinogens, may include in unknown quantities and combinations: crystalline silica, methanol, ethylene glycol, sodium hydroxide, butoxyethanol, naphthalene, isopropanol, diesel, hydro-treated light distillate, formaldehyde, sulfuric acid, benzene, lead, boric acid, fuel #2, kerosene, hydrofluoric acid, hydrochloric acid, formic acid, surfactants and a long list of various other chemicals. Yet, through exemptions granted and confirmed by the United States Congress to the oil and gas industry resulting from statutory amendments passed in 2005 to federal environmental laws governing safe drinking water and clean air,[3] the otherwise traceable effects of this chemically-laden fluid were deemed to be proprietary and therefore protected from public disclosure.

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[2] Hydraulic Fracturing Technological Milsestones, NYSSGEIS, revised draft, page 5-5, 2011.

[3] Energy Policy Act of 2005, Sec. 322. Hydraulic Fracturing, Paragraph (1) of section 1421(d) of the Safe Drinking Water Act (42 U.S.C. 300h [d]) is amended to read as follows: (1) Underground injection.—The term 'underground injection'— (A) means the subsurface emplacement of fluids by well injection; and (B) excludes—(i) the underground injection of natural gas for purposes of storage; and (ii) the underground injection of fluids or propping agents (other than diesel fuels) pursuant to hydraulic fracturing operations related to oil, gas, or geothermal production activities.)

(vi) These combined technologies are designed to extract methane gas locked inside mile or more deep, hundreds of millions of year old shale formations. Shale gas is separate and distinct from the conventional gas pools or reservoirs which flow freely underground and can be captured through conventional well extraction methods.

(vii) These combined technologies which have been in use for less than a decade, bring with them uniquely hazardous risks which are distinguishable from those characteristically associated with low-volume, conventional hydraulic fracturing. To state it, clearly and emphatically, based upon my personal, professional and academic knowledge in the field of petro engineering, high volume, slick water vertical and horizontal hydraulic fracturing from clustered, multi-well pads in shale plays is novel, unconventional and extremely dangerous.

(viii) Spokespersons for the oil and gas industry refer, rather slyly, to the older, low-volume gas drilling from single, isolated wells when asserting that hydraulic fracturing has been in practice and performed safely for decades.

(ix) Hydraulic fracturing is intended to, and does, release methane gas from shale; however, as the fracturing fluid flows back through the well, it also contains dissolved constituents such as minerals, brine and concentrated levels of heavy metals such as strontium, uranium, radium, barium and thorium.

(x) In addition, the hydraulic fracturing process results in the production of solid waste such as drill cuttings and drilling mud, which can contain high levels of naturally occurring radioactive material which are brought to the surface as a result of high volume hydraulic fracturing process. All of these elements add to the extraordinarily dangerous character of this multi-step process.

(xi) The introduction of this extraordinarily dangerous heavy industrial surface and sub-surface activity situated on expanses of land, for mile after mile, in multiple directions immediately adjacent to backyards and side yards of surface properties where families live and raise their children is novel, and unique.

(xii) High volume slick water hydraulic fracturing from clustered, multi-well pads involves a multi-step process with numerous risks, indeed, far more risk than the laying of pipelines and storing gas, because it involves additional processes which are extraordinarily hazardous and extremely dangerous, as explained below.

Abnormally Dangerous/Ultra Hazardous Aspects of Hydraulic Fracturing.

One can easily identify multiple activities in the lifecycle of the creation of a shale gas well that are extremely hazardous to life and property. In addition to the four examples given below, there are other steps of the gas extraction process after the gas well is created and once the gas is removed which also introduce extremely

hazardous conditions to life and property. These steps relate to the separation and processing of the gas and compression of the gas which are not the subject of this statement but which can be addressed separately to the court or at trial.

(i) First is the use of perforating explosives in the form of shaped charges. Shaped explosive charges were originally perfected for wide scale military use in the 1940's for purposes of penetrating tank armor and the like. The fabled "Bazooka" employed shaped-charge technology. In present military parlance, shaped charges are referred to as explosive anti-tank warheads, or HEAT. HEAT warheads are used in anti-tank guided missiles, unguided rockets, gun-fired projectiles, rifle grenades, land mines, torpedoes, and various other weapons. The charge ignites a propellant explosive which melts a metallic cone shaped liner, which in turn creates a high-temperature, high-velocity projectile of molten metal.

Shaped charge technology is used by the gas industry in well completion phases of gas operations, in preparation for shale gas extraction. In preparation for hydraulic fracturing and gas extraction, in a typical shale gas well, hundreds if not thousands of shaped explosive charges are run down the well and intentionally detonated in order to perforate the well's metal casing and cement first to admit the outward flow of hydraulic fracturing liquid, and later the influx of oil or gas, or both, after hydraulic fracturing.

Once triggered, these molten liquid projectiles move at a velocity of thousands of feet per second and generate temperatures in the thousands of degrees. These dangerous and volatile explosive devices must be handled with a high degree

of care, as with any dangerous explosive, while in transit to the well pad, while on the well pad and through completion of detonation. Specialized personnel, equipment protocols and safety procedures must be employed at all times in the handling and use of shaped charges during drilling operations. However, even under optimal conditions and in the absence of negligence, there have been instances of premature detonation of shaped charges both outside the well and inside the well. Incidents of accidental downhole detonation of shaped charges have occurred as recently as 2012.[4]

(ii) A second extremely hazardous activity during the well development process involves an uncontained blowout of the well A well blowout is loss of control by the operator of pressure in a well, leading to the forceful expulsion of introduced and native liquids and gases at very high flow rates and pressures. Blowout preventers (BOPs) are required by regulation to be installed during drilling and hydraulic fracturing. BOPs are supposed to be able to squeeze shut by mechanical means the casing string in which pressure control has been lost. As their name describes, blowout preventers are used to diminish the possibility of an uncontained blowout. However, BOP's do not always work, as in the Macondo accident in the Gulf of Mexico, and in at least two cases in the past few years in the Pennsylvania and West Virginia Marcellus operations. [5]

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[4] http://ercb.ca/reports/IR_20121220_Caltex.pdf

[5] http://www.portal.state.pa.us/portal/server.pt/community/newsroom/14287?id=12818&typeid=1; http://www.worldoil.com/Marcellus_well_suffers_a_blowout.html

(iii) This has the potential of being a particularly devastating and destructive type of accident with far reaching risks to life, limb and property.

Documented blowouts in Pennsylvania, West Virginia, Texas and other locations, involved explosion, fire, and ejection of machinery and dangerous liquids exceeding the dimensions of the well pad, i.e. hundreds of feet.[6] The reach of fire or explosion could extend thousands of feet or more. Extinguishing blowout-induced fire is extremely difficult because of the high pressure, flow rate, and temperature of the burning gas. Highly specialized contractors with unique equipment, tactics, and personnel—far beyond the capability of local first responders—are rushed to a site of an uncontrolled blowout. Blowout frequency varies with stage of drilling and particular operation, but can be as small as 1 in a thousand wells. Even under optimal conditions and in the absence of negligence, failures of the well blowout preventer have occurred during hydraulic fracturing operations in the state of Pennsylvania.

(iv) The third extremely hazardous activity associated with the lifecycle of developing a gas well has to do with the fracking process itself, during which very high pressure, at times more than 15,000 pounds per square inch, must exist for a prolonged period of time in the multitude of various flow-lines, pipelines, hoses, fittings and valves to inject fracking fluid from high-powered pumps into the well itself. This is extremely dangerous because if there is a failure of any one of these flow-lines, pipelines, hoses, fittings or valves, very high-pressure fluid would be

[6] http://www.drillingahead.com/page/2-killed-3-injured-in-texas-well-blowout

ejected and could be proven to be very dangerous-potentially life threatening-to humans on the well pad. Hence, only a minimal number of highly trained personnel can be on the well pad during fracking operations during which time constant measurements, inspections, and monitoring of all the frack equipment and safety equipment is required to be done. In addition, appropriate protocol includes daily safety meetings of all personnel working on the drill pad. The fracking process can also result in uncontained flow of frack fluid and hydrocarbons off the well pad resulting in potential injury/damage to person/property from the abnormally dangerous uncontrolled flow at high pressure. Even under optimal conditions and in the absence of negligence, accidents of the nature described have occurred during hydraulic fracturing operations in the Commonwealth of Pennsylvania.[7]

(v) A fourth extremely hazardous activity associated with the lifecycle of developing a gas well has to do with handling of gaseous emissions from the well during the fracking phase. During the flowback phase of fracking, a very large volume of methane gas in addition to potentially other volatile organic compounds are emitted from the well at high pressure (hundreds of pounds per square inch) These high speed emissions have to be captured and directed, sometimes into a flare stack for burning, sometimes directly into the atmosphere, and sometimes into flowback tanks which have to be vented.

[7] http://www.post-gazette.com/stories/local/marcellusshale/bradford-county-shale-well-spews-fluids-294

In each of these three alternatives, large volumes of gas under high pressure must be contained and directed. Any loss of control of flow might result in accidental ignition or explosion. Even under optimal conditions and in the absence of negligence, accidents of the nature described have occurred during hydraulic fracturing operations in the Commonwealth of Pennsylvania.[8]

16. The plaintiffs' residences and their drinking water sources are located within 1000 feet of Cabot's Gesford 3, Gesford 3S and Gesford 9, determined by Pennsylvania Department of Environmental Protection (PADEP) to have failed cement jobs, for which I might add, Cabot's well number designations, and well and drilling logs are extremely unclear. In addition, the Elys' water well is located within 2,500 feet of the following Cabot gas wells: Ely 2, Ely 1H, Ely 5H, Ely 7H, Costello 1, and possibly Gesford 7H; and the Huberts' water well is located within 2,500 feet of the following Cabot gas wells: Costello 1, Costello 2, Ely 2, Ely 1H, Ely 5H, Ely 7H, Gesford 2, Gesford 4, Gesford 7H and Gesford 8H, each of which is located within the "affected area" as designated by PA DEP.

17. Impacts from each of the foregoing four examples of abnormally dangerous and ultra-hazardous activity, could travel up to and beyond 2,500 feet from the above mentioned wells to physically harm the plaintiffs or materially adversely affect the plaintiffs' residences or their water supply, or both, even in the absence of the negligence which occurred in the construction of the wells in the nine square mile affected zone.

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[8] http://www.marcellus-shale.us/Marcellus-Shale_Fires.htm

18. The potential effect of the protection afforded to the oil and gas industry with respect to the undisclosed chemicals combined with the abnormally dangerous and ultra-hazardous processes described above could potentially result in the inability of those adversely impacted, potentially these plaintiffs, to make a definitive causal connection between an event and the harm caused.

19. In light of the multiple opportunities for human error or infrastructure failure resulting during any phase of the drilling and fracturing lifecycle, each of which can be considered dangerous even with the exercise of due care, it follows that the oil and gas industry should automatically take full financial responsibility for the damage caused during these operations over which it has exclusive control. Regular citizens living at the doorstep of oil and gas industry practices over which they have no control should be spared the added step of litigating to determine responsibility.

20. My opinions have been and are informed and rendered based upon my educational background, over three decades of professional involvement in the study and teaching of rock physics and hydraulic fracturing, reference and review of research and peer-reviewed publications of distinguished members of my profession, and analysis of pertinent documentary evidence in this case, including that provided by the Pennsylvania Department of Environmental Protection, e.g., four consent orders and agreements issued by the agency in 2009 and 2010, and the defendants themselves.

Date: June 17, 2013 Respectfully Submitted,

Anthony R. Ingraffea, PhD, P.E.

CURRICULUM VITAE

Anthony R. Ingraffea

Dwight C. Baum Professor of Engineering
Weiss Presidential Teaching Fellow
School of Civil and Environmental Engineering
Cornell University
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GENERAL

Born: April 4, 1947, Easton, Pennsylvania, USA
Residence: 309 Cayuga Heights Road, Ithaca, N.Y. 14850
Telephone: Home 607-257-1104 Office 607-255-3336 Cell 607-351-0043
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EDUCATION

University of Notre Dame
B.S., Aerospace Engineering, *Magna Cum Laude*, June 1969.
Polytechnic Institute of New York
M.S., Civil Engineering, Grumman Masters Fellow, June 1971.
University of Colorado/Boulder
Ph.D., Civil Engineering, May 1977, University Fellow, 1974-1976.

AREAS OF EXPERTISE

Structural Engineering, Structural Mechanics, Computational and Experimental Fracture Mechanics, Microstructural Simulation of Fatigue and Fracture Mechanisms, Rock Mechanics, Numerical Methods, Engineering Education

PROFESSIONAL EXPERIENCE

June 1969 - June 1971

Grumman Aerospace Corporation. Bethpage, L.I., N.Y.
Rotating traineeship in the following areas: preliminary design on Navy F - 14; loads and dynamic studies, stress analysis, and final design on NASA Space Shuttle proposal. Two in - house technical publications.

July 1971 - June 1973

Peace Corps. Bejuma, Venezuela
County Engineer. Responsible for all technical services to a county of 40,000 people. Directed surveying, design, and construction of farmers' market, tourist hotel, and cemetery. Directed urban planning resource study. Co - directed urban renewal plan and data collection for section of state capital city.

September 1973 - August 1977

University of Colorado/Boulder
Department of Civil, Environmental and Architectural Engineering
Instructor for Courses:
Analytical Mechanics, Theoretical Fluid Mechanics
Teaching Assistant for Courses:
Mechanics of Materials
Materials Testing Laboratory
Research Assistant in Project: Constitutive Relations for Coal

September 1977 - June 1982

Cornell University, Department of Structural Engineering
Assistant Professor

September 1979 - July 1983
Cornell University, Department of Structural Engineering
Manager of Experimental Research

July 1982 - June 1987
Cornell University, Department of Structural Engineering
Associate Professor

August 1983 - August 1984
Lawrence Livermore National Laboratory Livermore, California
Visiting Research Engineer: Rock Fracture Simulation

January 1986 - September, 1986
Cornell University, Computer Aided Design Instructional Facility,
College of Engineering
Director

September 1986 - October, 1990
Cornell University, College of Engineering
Faculty Coordinator for Instructional Computing

July 1987 - Present
Cornell University, School of Civil and Environmental Engineering
Professor

September 1987 - April 1992
Cornell University, Program of Computer Graphics
Associate Director

September 1988 - Present
Fracture Analysis Consultants, Inc.
President

October 1990 - October 1994
Cornell University
Director, NSF-Synthesis National Engineering Education Coalition

July 1993 - Present
Cornell University
Dwight C. Baum Professor of Engineering

October 1994 - October 1995
Cornell University
Associate Director, NSF-Synthesis National Engineering Education Coalition

December 1997 –August 2005
Cornell Center for Theory and Simulation in Science and Engineering
Associate Director
Coordinator, Computational Materials Institute

July 1998 – December 1999
Cornell University
Coordinator, Infrastructure Group, School of Civil and Environmental Engineering

November 2002-Present
Cornell University
Member, Graduate Fields of Mechanical and Aerospace Engineering

May 2004-Present
Wright Patterson Air Force Base/AFRL/Air Vehicle Directorate/Structures Division
Structural Sciences Center of Excellence
Visiting Scientist

August 2005 – July 2007
Cornell University
Acting Director, Cornell Center for Theory and Simulation in Science and Engineering

November 2005 – Present
Cornell University
Weiss Presidential Fellow

July 2006 – December 2007
Cornell University
Coordinator, Infrastructure Group, School of Civil and Environmental Engineering

August 2005 – Present
Cornell University
Co-Editor in Chief, *Engineering Fracture Mechanics*

August 2010 – Present
Physicians, Scientists, and Engineers for Sustainable and Healthy Energy, Inc.
President

AWARDS AND HONORS

- **3 - M Corporation Scholarship**, 1965 - 1969
- **Grumman Masters Fellowship**, 1969 - 1971
- University of Colorado **Graduate Fellowships**, 1974 - 1976
- Cornell School of Civil Engineering **"Professor of the Year,"** 1977 - 78
- National Research Council/U.S. National Committee for Rock Mechanics 1978 **Award for Outstanding Research in Rock Mechanics at the Doctoral Level**
- Cornell College of Engineering **"Professor of the Year,"** 1978 - 79
- Cornell School of Civil Engineering **"Professor of the Year,"** 1981 - 82
- **Presidential Young Investigator Award**, National Science Foundation, 1984 - 1989
- **Dean's Prize for Innovation in Teaching**, Cornell College of Engineering, 1989.
- **Dean's Prize for Innovation in Teaching**, Cornell College of Engineering, 1991.
- National Research Council/U. S. National Committee for Rock Mechanics **1991 Award for Applied Research** for the paper, "Simulation of Hydraulic Fracture Propagation in Poroelastic Rock with Application to Stress Measurement Techniques", co-authored by Dr. T. J. Boone, *Int. J. Rock Mech. Min. Sci. & Geomech. Abstr.*, 28, 1, 1-14, 1991.
- International Association for Computer Methods and Advances in Geomechanics **1994 Significant Paper Award**: One of Five Significant Papers in the category of Computational/Analytical Applications in the past 20 years, "A Numerical Procedure for Simulation of Hydraulically-driven Fracture Propagation in Poroelastic Media", co-authored with T. J. Boone, *Int. J. Num. Analyt. Meth. in Geomech.,* 14, 1, 1990.
- The **NASA Group Achievement Award** for contributions, with former students Drs. Paul Wawrzynek and David Potyondy, to the Fuselage Structural Integrity Analysis Team, NASA Langley Research Center, 1996.
- The First **Society of Women Engineer's Professor of the Year Award**, Cornell College of Engineering, 1997.
- **J. P. and Mary Barger '50 Excellence in Teaching Award**, Cornell College of Engineering, 1997.
- The **MTS Visiting Professor Chair**, Department of Civil Engineering, University of Minnesota, May, 1998.
- **Aviation Safety Turning Goals into Reality Award**, NASA Airframe Structural Integrity Program Team, NASA Langley Research Center, with Dr. Paul Wawrzynek, 1999.
- **1999 Premier Award for Educational Software** for "Cracking Dams-HTTP://www.simscience.org", with Megann Polaha
- **Daniel Luzar '29 Excellence in Teaching Award**, Cornell College of Engineering, 2001.

- **Honor Award, University of Notre Dame,** College of Engineering, for "Significant Contributions to the Advancement of Engineering", 2002.
- **Weiss Presidential Teaching Fellow,** Cornell University, 2005.
- **George R. Irwin Medal**, American Society for Testing and Materials, 2006.
- **Richard J. Almeida Award, Project High Jump,** given each year to an individual whose dedication and contribution to High Jump have been extraordinary, 2008.
- **Fellow, International Congress on Fracture,** 2009, "For his pioneering contributions to the advanced computational simulation of fatigue and fracture processes leading to improved understanding for practical applications to integrity assessment of engineering structures".
- One of **TIME** Magazine's **"People That Mattered"** in 2011.

HONORARY/PROFESSIONAL SOCIETY MEMBERSHIP

Tau Beta Pi (1967 -
Chi Epsilon (1974 -
Sigma Xi (1977 -
American Academy of Mechanics (1988 -
American Society of Civil Engineers (**Fellow, 1991**)
  Chairman, Committee on Properties of Materials (1983 - 1985)
  Member, Committee on Finite Element Analysis of Reinforced Concrete
  Member, Committee on Computer Applications and Numerical Methods
International Society for Boundary Elements
International Society for Rock Mechanics
Society for Experimental Mechanics
American Society for Testing and Materials
  Committee E - 8 on Fracture and Fatigue
  Committee D - 18 on Soil and Rock for Engineering Purposes
  Committee C - 9 on Concrete
American Concrete Institute
  Committee 446 on Fracture Mechanics
RILEM
  Committee 90 - FMA on Fracture Mechanics Applications
  Member, Committee 89 - FMT on Fracture Mechanics Testing
American Rock Mechanics Association/Foundation
    Founding Member
    Member of the Board, 1999-2003

PROFESSIONAL REGISTRATION

Colorado	PE No. 14837
New York	PE No. 081309-0
Alaska	Professional Fishing Guide

UNITED STATES PATENT

Number 481,826, Hand - held, direct reading, fully mechanical fracture loading device for short-rod/bar specimens

PROFESSIONAL JOURNAL EDITORSHIPS AND ADVISORY BOARDS

Co-Editor-in-Chief:
Engineering Fracture Mechanics, August, 2005-present

Editorial Advisory Board:
International Journal for Numerical and Analytical Methods in Geomechanics
Boundary Element Communications
Engineering with Computers
Engineering Computations
International Journal for Multiscale Computational Engineering

PUBLICATIONS

TEXTS EDITED

1. **Fracture Mechanics of Concrete: Material Characterization and Testing**, co - edited with A. Carpinteri, Martinus Nijhoff Publishers, 1984.

PUBLISHED IN TEXTS

1. Ingraffea, A R (co - author). Modelling of Reinforcement and Representation of Bond. Chapter 3 in **Finite Element Analysis of Reinforced Concrete,** State - of - the - Art report prepared by the Task Committee on Finite Element Analysis of Reinforced Concrete Structures, Structural Division, ASCE, 1982, pp. 149 - 203.

2. Ingraffea A R (co - author). Concrete Cracking. Chapter 4 in **Finite Element Analysis of Reinforced Concrete**. State-of-the-Art report prepared by the Task Committee on Finite Element Analysis of Reinforced Concrete Structures, Structural Division, ASCE, 1982, pp. 204 - 233.

3. Ingraffea A R. Numerical Modelling of Fracture Propagation. Chapter 4 in **Rock Fracture Mechanics**, H. P. Rossmanith, editor, CISM Courses and lectures No. 275, International Center for Mechanical Sciences, Udine, Italy, Springer - Verlag, Wien - New York, 1983, pp. 151 - 208.

4. Ingraffea A R, Saouma V. Numerical Modeling of Discrete Crack Propagation in Reinforced and Plain Concrete. Chapter 4 in **Application of Fracture Mechanics to Concrete Structures: Structural Application and Numerical Calculation,** G. C. Sih and A. DiTommaso, editors, Martinus Nijhoff Publishers, 1984.

5. Ingraffea A R, Gerstle W. Non - Linear Fracture Models for Discrete Crack Propagation. **Application of Fracture Mechanics to Cementitious Composites,** S. P. Shah, editor, Martinus Nijhoff Publishers, 1985, pp. 171 - 209.

6. Ingraffea A R. Fracture Propagation in Rock. Chapter 12 in **Mechanics of Geomaterials,** Z. P. Bazant, editor, John Wiley & Sons, Limited, 1985.

7. Ingraffea A R. Theory of Crack Initiation and Propagation in Rock. Chapter 3 in **Rock Fracture Mechanics**, B. Atkinson, editor, Academic Press, Inc., 1987.

8. Ingraffea A R, Gerstle W H, Perucchio R. Fracture Analysis with Interactive Computer Graphics. **Boundary Element Methods in Structural Analysis**, D. E. Beskos, Editor, ASCE, 1989, pp. 235 - 271.

9. Ingraffea A R, Sections 9.3, 12.3, 13.4, and 15.2, of **Fracture Mechanics of Concrete Structures: From Theory to Applications**, L. Elfgren, Editor, Chapman and Hall, London, 1989.

10. Ingraffea A R, Boone T J, Swenson D V. Computer Simulation of Fracture Processes. Chapter 22 in **Comprehensive Rock Engineering,** J. Hudson, Editor-in-Chief, Pergamon Press, Oxford, 1993.

11. Carter B J, Desroches J, Ingraffea A R, Wawrzynek P A. Simulating Fully 3D Hydraulic Fracturing. In **Modeling in Geomechanics**, Ed. Zaman, Booker, and Gioda, Wiley Publishers, pp 525-557, 2000.

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49. P. Wawrzynek, Ingraffea, A., "FRANC2D: A Two-Dimensional Crack Propagation Simulator Version 2.7 User's Guide", NASA Contractor Report 4572, National Aeronautics and Space Administration, Langley Research Center, Hampton, VA, March, 1994, 59 pp.

50. "Fracture Mechanics Life Analytical Methods Verification Testing-Final Report", NAS8-38103, for the George C. Marshall Space Flight Center, NASA, Nichols Research Corporation/Cornell University/ Fracture Analysis Consultants, Inc., 1994.

51. Chi, W-M, Dierlein, G., Ingraffea, A. R., "Finite Element Fracture Mechanics Investigation of Welded Beam-Column Connections", SAC Joint Venture/CUREe Subcontract 26-28, Structural Engineering Report No. 97-7, Cornell University, Ithaca, NY, 167 pp.

52. Chen, C.-S., Wawrzynek, P.A., and Ingraffea, A. R., "Crack Growth Simulation and Residual Strength Prediction in Airplane Fuselages," Final Report for NASA project NAG-1-1184, Structural Engineering Research Report 99-1, School of Civil and Environmental Engineering, Cornell University, January, 1999.

53. Hwang, C., Ingraffea, A. R., Wawrzynek, P., "Virtual Crack Extension Method for Calculating Rates of Energy Release Rate and Numerical Simulation of Crack Growth in Two and Three Dimensions", Structural Engineering Research Report 99-2, School of Civil and Environmental Engineering, Cornell University January, 1999.

54. Hanson, J. H., Ingraffea, A. R., "Proposed Standard Test Method for Round Double Beam Fracture Toughness of Concrete," *Research Report*, 00-1, Department of Structural Engineering, Cornell University, Ithaca, NY, Jan. 2000.

55. Chen, CS, Wawrzynek, PA, and Ingraffea, AR. "Finite Element Stress Analysis Subroutines for RAPID", Final Report to Federal Aviation Administration, Project DTFA0300C00002, 2000.

56. Lewicki, DG, Spievak, L, Wawrzynek, PA, Ingraffea, AR, Handshuh, R, "Consideration of Moving Tooth Load in Gear Crack Propagation Predictions", NASA/TM-2000-210227, ARL-TR-2246, DETC2000/PTG-14386, July, 2000.

57. Iesulauro E, Ingraffea AR. "Computational Micro-Mechanical Investigations of Crack Initiation in Metallic Polycrystals", NASA Langley Research Center, Final Report on Project NAG-1-0205, July 21, 2006, 210 pages.

58. Ingraffea AR, Tuegel E. "Structural Life Forecasting in Extreme Environments", Structural Sciences Center, AFRL/RBSM, Wright Patterson AFB, Dayton, Ohio, October, 2009.

59. Spear AD, Priest AR, Veilleux MG, Hochhalter JD, Ingraffea AR. Surrogate modeling of high-fidelity fracture simulations for real-time residual strength predictions, NASA TM-2011-216879, 2011.

FUNDED RESEARCH PROJECTS

Structural Engineering

1. "An Investigation into Mixed - Mode Fracture Propagation in Rock," National Science Foundation Research Initiation Grant ENG78 - 05402, 4/78 - 3/80, $25,000, Principal Investigator.

2. "Finite Element Analysis of Reinforced Concrete for Cyclic Loading," National Science Foundation Grant PFR - 7900711, 4/79-3/81, $84,000, Principal Investigator. P. Gergely and R. N. White, Co - Principal Investigators.

3. "Laboratory Testing of the Crack - at - an - Interface Problem," Sandia National Laboratories Contract No. 13 - 5038, 5/79 - 5/80, $42,000, Principal Investigator.

4. "Three - Dimensional Interactive Computer Graphics in Structural and Geo - Mechanics," National Science Foundation Grant CME79 - 16818, 1/80 - 6/82, $500,000, Faculty Investigator. J. F. Abel, D. P. Greenberg, W. McGuire, Co-Principal Investigators; F. H. Kulhawy, Faculty Investigator.

5. "Interaction Between Steel and Concrete for Earthquake-Type Loadings," National Science Foundation Grant CME80 - 20925, 4/1/81 - 9/30/83, $140,000, Principal Investigator. P. Gergely, Co - Principal Investigator.

6. "Interactive Color Display of Three - Dimensional Engineering Analysis Results," National Aeronautics and Space Administration, Grant NAG3 - 395, 3/1/83 - 2/28/87, $133,285, Associate Investigator. J. F. Abel, Principal Investigator.

7. "Welded Crane Runway Girder Study," Association of Iron and Steel Engineers, 8/83 - 8/85, $234,348, Principal Investigator. W. McGuire, T. Pekoz, Co - Principal Investigators.

8. Presidential Young Investigator Award in Structural Mechanics, National Science Foundation Grant 8351914, 6/84 - 6/89, $500,000, Principal Investigator.

9. "Fatigue Behavior of Thick Steel Plates," Electric Boat Division/General Dynamics, PO# R2041 - 907, 1/86 - 12/88, $233,218, Co - Principal Investigator. R. N. White, Principal Investigator.

10. "Probabilistic Fracture Mechanics," AFOSR, 4/87 - 4/90, $269,624, Co - Principal Investigator. M. Grigoriu, Co - Principal Investigator.

11. "CISE Research Instrumentation: Computer Graphics Dynamic Simulation for Scientific Inquiry," National Science Foundation Grant CCR - 8717024, 4/1/88 - 9/30/89, $145,600, Co - Principal Investigator. M. Cohen, D. Greenberg, and J. Abel, Co - Principal Investigators.

12. "Visualization for Supercomputing: A Graphics Workstation Approach," National Science Foundation, Grant ASC - 8715478, 8/1/88 - 1/31/90, $202,532, Co - Principal Investigator. D. Greenberg, Principal Investigator. J. Abel, M. Cohen, D. Caughey, Co - Principal Investigators.

13. "Advanced Computational Fracture Mechanics," Digital Equipment Corporation, 7/89 - 7/90, $100,000, Principal Investigator.

14. "Fatigue and Damage Tolerance", Northrop-Grumman Corporation, 6/89-12/00, $249,000, Principal Investigator.

15. "Research in Fracture Mechanics", Exxon Education Foundation, 9/89-9/92, $30,000, Principal Investigator.

16. "Crack Growth Prediction Methodology for Multi-Site Damage", NASA Langley Research Center, 9/90-9/98, $926,147, Principal Investigator.

17. "Fracture Mechanics Life Analytical Methods Verification Testing", Nichols Research Corp. /NASA MSFC, 8/91 - 8/94, $183,860, Principal Investigator.

18. "Mode I/III Fatigue Crack Growth Measurements in 2024 Aluminum Sheet", NASA Langley Research Center, 6/91-9/93, $159,836, Co-Principal Investigator. A. Zehnder, Co-Principal Investigator.

19. "A Study of Failure Mechanisms of Advanced Flex Cables", IBM Corporation, 1/20/92-1/19/93, $25,000, Co-Principal Investigator. A. Zehnder, Co-Principal Investigator.

20. "Detecting Cracks in Concrete Dams", U. S. Army Engineer Waterways Experiment Station, 4/1/94-1/1/95, $39,339, Co-Principal Investigator. M. Sansalone, Principal Investigator.

21. "Measurement of Fracture Toughness of Concrete Using the Short-Rod Procedure", NSF CMS 9414243, 9/95-8/98, $203,854. Principal Investigator.

22. "Simulation of Damage Tolerance in Honeycomb Core Structure", Boeing Commercial Airplane Co., 5/96-12/98, $204,000. Principal Investigator.

23. "Simulation of Crack Growth in Spiral Bevel Gears", NASA Glenn Research Center, 12/96-12/00, $289,961. Principal Investigator.

24. "Fracture of Steel Joints", CUREe SAC Phase II Subcontract No. 28, 9/96-12/96, $23,000. Co-Principal Investigator. Prof. G. Deierlein, Principal Investigator.

25. "Multidisciplinary Center for Earthquake Engineering Research", NSF, 10/97-9/02, $1,500,000. Associate Investigator. Prof. R. White, Co-Principal Investigator; Profs. G. Deierlein, M, Grigoriu, Associate Investigators.

26. "Simulation of Crack Propagation on Teraflop Computers", NSF, 1/98-12/00, $1,800,000. Co-Principal Investigator. Profs. S. Vavasis and K. Pingali, Co-Principal Investigators.

27. "Probabilistic Simulation of Fatigue Crack Initiation", AFOSR, 3/98-2/01, $600,000. Principal Investigator. Profs. M. Grigoriu, M. Miller, P. Dawson, Co-Principal Investigators.

28. "Development and Implementation of T-Stress Criterion", NASA Langley Research Center, 8/97-3/98, $20,128. Principal Investigator.

29. "Crack Turning and Arrest Mechanisms for Integral Structures", NASA Langley Research Center, 1/98-6/00, $103,642. Principal Investigator.

30. "Basic Research in Crack Growth Prediction Methodologies", NASA Langley Research Center, 1/98-11/99, $185,000. Principal Investigator.

31. "Fatigue Crack Growth in Aluminum Alloys", Alcoa Foundation, 6/97-5/98, $10,000. Principal Investigator.

32. "Multiscale Modeling of Defects in Solids", NSF 9873214, 10/98-9/01, $1,500,000. Co-Principal Investigator. Profs. P. Dawson, and J. Sethna Co-Principal Investigators, C. Myers, Co-Principal Investigator.

33. "A Two-Tier Computation and Visualization Facility for Multiscale Problems", NSF 9972853, 10/99-9/04, $1,500,000. Co-Principal Investigator. Profs. K. Pingali, N. Chrisochoides, C. Cruz-Neira, Guang Gao, Co-Principal Investigators.

34. "Finite Element Stress Analysis Subroutines for RAPID", Federal Aviation Administration, 9/99-4/2000, $34,438. Principal Investigator.

35. "Finite Element/Fracture Mechanics Simulation of Trajectories During Slitting of Plastic Films", Eastman Kodak Company, 1/1/99-12/31/01, $110,000. Principal Investigator.

36. "ITR: Adaptive Software for Field-driven Simulations", NSF 0085969, 9/1/00-8/31/04, $5,000,000. Co-Principal Investigator. Prof. K. Pingali, PI, B. K. Soni, J. F. Thompson S. A. Vavasis, Co-PIs.

37. "Developing Technologies for Modeling Damage in Stiffened Thin Shell Structures", NASA LaRC, 11/1/01-10/31/04, $160,107. Principal Investigator.

38. "Computational Micro-Mechanical Investigations of Crack Initiation in Metallic Polycrystals", NASA LaRC, 2/1/02-1/31/05, $230,182. Principal Investigator.

39. "The Institute for Future Space Transport", NASA Marshall RC University Research, Engineering and Technology Institute, 8/1/02-9/15/07, $15,616,120, Co-Principal Investigator. W. Shyy, Principal Investigator, B. Soni, B. Davidson, J. Olds, Co-Principal Investigators.

40. "Structural Integrity Prognosis System-SIPS", DARPA, 10/1/03-8/31/08, $1,288,400, Cornell Principal Investigator. J. Madsen, Northrop Grumman Corp. Project Manager.

41. "Fracture Mechanics Analysis of MANPADS-Damaged Aircraft Structures", NASA LaRC, 5/05-9/06, $74,000. Principal Investigator.

42. "Advanced Digital Material Machine (ADMM) "AFOSR/DURIP, 2006, $300,000. Principal Investigator.

43. "Multi-Scale Simulation of Cracking Processes in Metallic Materials", NASA LaRC, NNX07AB69A, 1/07-12/10, $392,526. Principal Investigator.

44. "Constellation University Institute Project: Computational Simulation of Damage Tolerance for Composite and Metallic Structures", NASA, 10/1/07-9/30/10, $450,000, Principal Investigator.

45. "Multi-scale Simulation of Fatigue Damage", Northrop Grumman Corporation, 1/1/07-12/31/09, $55,000, Principal Investigator.

46. "Computational Methods in Physics-Based Modeling of Damaged Flight Structures", NASA LaRC NNX08AC50A, 1/1/08-12/31/2010, $299,972, Principal Investigator.

47. "Collaboration between Cornell Fracture Group and Exponent, Inc.", Exponent Inc., 3/08-12/08, $29,204, Principal Investigator.

48. "Geometrical Simulation of Complete Process of Microstructurally Small Fatigue Cracking" E DARPA, HR0011-09-1-0002, 1/09-12/09, $150,000, Principal Investigator.

49. "Parallel File Serving R&D", IBM, $20,200, 7/09-6/10, Principal Investigator.

50. "Prognosis of Long-Term Load-Bearing Capability in Aerospace Structures: Quantification of Microstructurally Short Crack Growth", Air Force Office of Scientific Research, $750,000, 5/10/5/13, Co-Principal Investigator.

Geotechnical Engineering

1. "TBM Performance Study," U.S. Dept. of Transportation, 3/80 - 3/82, $164,000, Associate Investigator. T. D. O'Rourke, Principal Investigator; F. H. Kulhawy, Associate Investigator.

2. "A Study of Cast Iron Gas Main Replacement," New York Gas Group, 8/81 - 12/83, $287,000, Associate Investigator. T. D. O'Rourke, Principal Investigator; F. H. Kulhawy, Associate Investigator.

3. "Uplift/Compression Transmission Line Structure Foundation Research," Electric Power Research Institute, RP1493 - 4, 1984 - 1988, $2,450,000, Associate Investigator. F. H. Kulhawy, Principal Investigator; T. D. O'Rourke, M. Grigoriu, Associate Investigators.

4. "Numerical Investigations into Crack Propagation in Rock," National Science Foundation Grant CEE - 8316730, 6/1/84 - 5/30/86, $150,000. Principal Investigator

5. "Workshop on Interactive Computer Modeling and Graphics for the Design and Optimization of Field and Laboratory Experiments in Geotechnical Engineering." National Science Foundation Grant CEE 8413471, 12/84 - 11/86, $39,681. Principal Investigator.

6. "Evaluation of Cased and Uncased Gas Distribution and Transmission Piping Under Railroads and Highways, Gas Research Institute, 11/86 - 1/94, $ 3,602,035. Co-Principal Investigator. T. D. O'Rourke and H. Stewart, Co-Principal Investigators.

7. "Influence of Perforations Upon Subsequent Hydraulic Fracturing," Digital Equipment Corp. and Dowell Schlumberger, 1/88 - 12/96, $448,000. Principal Investigator.

8. "Computational Simulation of Hydrofracturing", NSF CISE Postdoctoral Associate Award for Dr. K. Shah. 11/95-10/97, $46,200. Principal Investigator.

9. "3D Crack Initiation and Propagation in Transparent Rock Like Materials Loaded in Compression", NSF, 9/96-8/99, $148,000. Principal Investigator.

Engineering Education

1. "Study of Complementary Research and Teaching in Engineering Science - PROJECT SOCRATES," U. S. Department of Education, Fund for the Improvement of Post - Secondary Education, G 008642170, 9/15/86 - 9/14/89, $236,496, Project Director.

2. "Workstations For Instructional Computing in the College of Engineering," Digital Equipment Corporation, 5/1/88 - 4/31/90, $664,000. Project Director.

3. "Workstations for Project SOCRATES," Apollo Computer, Inc., June, 1989, $87,105. Project Director.

4. "Workstations for Project SOCRATES", Sun Microsystems, Inc., June, 1990, $89,415. Project Director.

5. "Synthesis National Engineering Education Coalition", National Science Foundation, 9/30/90 - 9/30/94, $12,278,036. Project Director.

6. "1992 Summer Institute for Computer Graphics", New York State Education Department, $56,000, 7/19/92-8/8/92, Project Co-Director. C. Mink, Director.

7. "Support for Educational Computing Equipment", Hewlett Packard, 6/92, $427,318. Project Director.

8. "Synthesis Coalition/GE Foundation Faculty Exchange Award", GE Foundation, Spring 1994 - Spring 1997, $230,000, Principal Investigator.

9. "Synthesis Coalition/Raytheon Company Student Award" Raytheon Company, 1994-1995, $24,000, Principal Investigator.

10. "Application and Infrastructure Linkage to Altoona Area School District and Manhatten Center for Science and Math High School", Synthesis Coalition/NSF/GE Foundation/Mr. A. Misciagna, 10/1/94-9/30/96, $284,000, Project Director.

11. "Integration of Information Age Networking and Parallel Supercomputer Simulations into University and General Science K-12 Curricula", NSF, 1/96-12/98, $102,000, Co-Principal Investigator. J. Sethna, Co-Principal Investigator.

12. REU Supplement to "Measurement of Fracture Toughness of Concrete Using the Short-Rod Procedure", NSF, 9/95-9/98, $10,000, Principal Investigator.

13. REU Supplements to "Integration of Information Age Networking and Parallel Supercomputer Simulations into University and General Science K-12 Curricula", NSF, 9/96-9/98, $20,000, Co-Principal Investigator with Prof. James Sethna, Physics.

14. "Tech City Exhibition", NSF, 7/98-6/01, $639,543, Co-Principal Investigator. Dr. C. Trautmann, Principal Investigator.

15. "An Advanced Interactive Discovery Environment for Engineering Education" NASA/New York State/AT&T, 2/1/01-12/31/07, $4,300,000, Co-Principal Investigator. Prof. B. Davidson, Principal Investigator, Prof. E. Liddy, Co-PI.

16. "An IGERT Training Program In Sustainable Energy Recovery From The Earth-Education At The Intersection Of Geosciences And Engineering". July 2010-June 2015, National Science Foundation, $1,137,047. Co-Principal Investigator. Prof. Jeff Tester, Principal Investigator, Profs. Terry Jordan, Paulette Clancy, Co-PI's.

Co-operative Research

1. "Co-operative Agreement between Cornell University and the Technical University of Delft", National Science Foundation Grant PFR-8020924, 1/81 - 12/82, $25,800, Co - Principal Investigator. P. Gergely, Principal Investigator; R. N. White, Co – Principal Investigator.

2. "Scientific Visit to Plan Co-operative Research in Hydraulic Fracturing," Catholic University of Rio de Janiero/Cornell University, National Science Foundation Grant INT - 8814466, July 1988, $2,336, Principal Investigator.

3. "Fracture Mechanics Case Studies of Concrete Dams" Technical University of Vienna, Austria/Cornell University, National Science Foundation Grant INT-8814457, 2/89 - 2/92, $8,080, Principal Investigator.

4. International Supplement to National Science Foundation Grant "ITR: Adaptive Software for Field-driven Simulations", to collaborate with Czech Technical University, Z. Bittnar, Czech Co-PI, 7/99-8/03, $24,375, Co-Principal Investigator.

THESES DIRECTED

Master of Science

1. "A Fracture Mechanics Analysis of the Fontana Dam," John Chappell, May, 1981.

2. "Mixed-Mode Crack Propagation in Mortar and Concrete." Manrique Arrea, January 1982.

3. "The Fracture Mechanics of Bond in Reinforced Concrete," Walter Gerstle. May 1982.

4. "Concrete Fracture: A Linear Elastic Fracture Mechanics Approach," David Catalano, August, 1982.

5. "Interactive and Graphic Two - Dimensional Fatigue Crack Propagation Analysis Using Boundary Element Method," Kodwo Otsei;du, January, 1983.

6. "An Experimental Investigation of Fatigue Cracking in Welded Crane Runway Girders Due to Wheel Induced Stresses," Kirk I. Mettam, January, 1986.

7. "An Investigation of the Failure Process of the STEM - PMMA Interface in Cemented Prostheses," Leonard Daniel - Timmie Topoleski, June 1986.

8. "Interactive Finite Element Analysis of Fracture Processes: An Integrated Approach," Paul A. Wawrzynek, May 1987.

9. "Analytical Study of Stresses in Transmission and Distribution Pipelines Beneath Railroads," J. Russell Blewitt, May 1987.

10. "Case Studies of Cracking of Concrete Dams--A Linear Elastic Approach," Shan - Wern Steve Lin, January 1988.

11. "Fracture Analysis Code: A Computer - Aided Teaching Tool," Maya Srinivasan, January 1988.

12. "Two-Dimensional Numerical Evaluation of Near Wellbore Phenomena: Perforation Performance & Interacting Hydraulic Fractures", Stephen James Lamkin, May 1990.

13. "On Finite Element Analysis of Face Sheet Cracking in Honeycomb Core Sandwich Panels", Kenneth Ferguson, January 1999.

14. "Simulating Fatigue Crack Growth in Spiral Bevel Gears", Lisa Eron Spievak, August 1999.

15. "Cracking Dams: An Interactive Web Site for K12", Megann V. Polaha, August 1999.

16. "Experimental Investigations into Damage Tolerance of Honeycomb Sandwich Panels", Ani Ural, August, 1999.

17. "Simulations of Crack Initiation in Aluminum Alloys with Inclusions", Ketan Dodhia, January, 2002.

18. "Decohesion of Grain Boundaries in Statistical Representations of Aluminum Polycrystals", Erin Iesulauro, January, 2002.

19. "An Evaluation of Surface Cracks in Welded Components of Nuclear Reactor Vessels", John Emery, May, 2003.

20. "Microstructural Reconstruction and Three-Dimensional Mesh Generation for Polycrystalline 7075-T651 Aluminum Alloy", Michael Veilleux, May, 2007.

21. "A Two-Dimensional Multiscale Method for Fatigue Crack Nucleation in Polycrystalline Aluminum Alloys ", Jeffrey Bozek, May, 2007.

Doctor of Philosophy

1. "Three-Dimensional Finite Element Analysis of Cyclic Fatigue Crack Growth of Multiple Surface Flaws." Corneliu Manu, June, 1980. Professor (Retired) University of Toronto.

2. "Automatic Two-Dimensional Quasi-Static and Fatigue Crack Propagation Using the Boundary Element Method." George E. Blandford, January, 1981. Professor, University of Kentucky.

3. "Interactive Finite Element Analysis of Reinforced Concrete: A Fracture Mechanics Approach," Victor E. Saouma, January, 1981. Professor, University of Colorado/Boulder.

4. "An Integrated Boundary Element Analysis System with Interactive Computer Graphics for Three - Dimensional Linear Elastic Fracture Mechanics," Renato S. Perucchio, January, 1984. Professor, University of Rochester.

5. "Finite and Boundary Element Modelling of Crack Propagation in Two- and Three - Dimensions Using Interactive Computer Graphics," Walter H. Gerstle, January, 1986. Professor, University of New Mexico.

6. "Modeling Mixed - Mode Dynamic Crack Propagation Using Finite Elements," Daniel V. Swenson, January 1986. Professor, Kansas State University.

7. "Simulation of Crack Propagation in Poroelastic Rock with Application to Hydrofracturing and *In - Situ* Stress Measurement," Thomas J. Boone, January, 1989. VP of Research, EXXON.

8. "Topological and Geometrical Modeling Approach to Numerical Discretization and Arbitrary Fracture Simulation in Three-Dimensions," Luiz Martha, August, 1989. Professor, Catholic University of Rio de Janeiro, Brazil.

9. "Numerical Methods for Hypersingular and Near-Singular Boundary Integrals in Fracture Mechanics", Earlin Lutz, May, 1991. Senior Research Engineer, Bentley, Inc.

10. "Discrete Modelling of Crack Propagation: Theoretical Aspects and Implementation Issues in Two and Three Dimensions", Paul A. Wawrzynek, August, 1991. Chief Engineer, Fracture Analysis Consultants, Inc.

11. "Three-Dimensional Simulation of Near-Wellbore Phenomena Related to Hydraulic Fracturing from a Perforated Wellbore", José Sousa, May, 1992. Professor, University of Campinas, Brazil.

12. "Computer Simulation of Linear and Nonlinear Crack Propagation in Cementitious Materials", Tulio Bittencourt, May, 1993. Professor, University of Sao Paulo, Brazil.

13. "A Methodology for Simulation of Curvilinear Crack Growth in Pressurized Shells", David Potyondy, August, 1993. Senior Research Engineer, Itasca, Inc.

14. "Experimental Validation Testing of Numerical Prediction Techniques for Three-Dimensional Fracture and Fatigue", William Riddell, June, 1995. Assoc. Professor, Rowan University.

15. "Crack Growth Simulation and Residual Strength Prediction in Thin Shell Structures", Chuin-Shan Chen, January, 1999. Assoc. Prof., National Taiwan University.

16. "Virtual Crack Extension Method for Calculating Rates of Energy Release Rate and Numerical Simulation of Crack Growth in Two and Three Dimensions", Changyu Hwang, January, 1999. Professor, Seoul University of Venture and Information.

17. "Crack Turning in Integrally Stiffened Aircraft Structures", Richard Pettit, August, 2000. Chief Engineer, FractureLab, LLC.

18. "An Experimental-Computational Evaluation of the Accuracy of Fracture Toughness Tests on Concrete", James Hanson, August, 2000. Assoc. Prof., Rose-Hulman Institute of Technology.

19. "Interface Modeling of Composite Material Degradation", Tong-Seok Han, May, 2001 (with Prof. Sarah Billington). Research Engineer, Korea Electric Power Research Institute.

20. "Modeling and Simulation of Fatigue Crack Growth in Metals Using LEFM and a Damage-Based Cohesive Model", Ani Ural, May, 2004 (with Prof. Katerina Papoulia). Assistant Professor, Villanova University.

21. "Decohesion of Grain Boundaries in Statistical Representations of Aluminum Polycrystals", Erin Iesulauro, May, 2006. Staff Engineer, Los Alamos National Laboratory.

22. "A Hierarchical, Probabilistic, Damage and Durability Simulation Methodology", John Emery, May, 2007, Staff Engineer, Sandia National Laboratory.

23. "Finite Element Simulation of Fatigue Crack Stages in AA 7075-T651 Microstructure", Jacob Hochhalter, May, 2010, Staff Engineer, NASA Langley Research Center.

24. "Geometrically explicit finite element modeling of AA7075-T651 microstructure with fatigue cracks", Michael Veilleux, August, 2010, Senior Member of Technical Staff, Sandia Livermore National Laboratory.

25. "Microstructural Simulation of Fracture Processes in Cortical Bone", Erin Oneida, December, 2013 (expected).

26. "Residual Strength of Damaged Aerostructures", Ashley Spear, NSF Graduate Fellow, May, 2013 (expected).

27. "DDSim for Composite Structures", Brett Davis, May, 2013 (expected).

28. "Geometrical Simulation of Complete Process of Microstructurally Small Fatigue Cracking ", Albert Cerrone, December 2013 (expected).

CURRICULUM VITAE

Anthony R. Ingraffea

Dwight C. Baum Professor of Engineering
Weiss Presidential Teaching Fellow
School of Civil and Environmental Engineering
Cornell University
Ithaca, N.Y. 14853 USA

GENERAL

Born: April 4, 1947, Easton, Pennsylvania, USA
Residence: 309 Cayuga Heights Road, Ithaca, N.Y. 14850
Telephone: Home 607-257-1104 Office 607-255-3336 Cell 607-351-0043
Fax: 607-255-9004 E-Mail: ari1@cornell.edu HTTP://www.cfg.cornell.edu

EDUCATION

University of Notre Dame
B.S., Aerospace Engineering, *Magna Cum Laude*, June 1969.
Polytechnic Institute of New York
M.S., Civil Engineering, Grumman Masters Fellow, June 1971.
University of Colorado/Boulder
Ph.D., Civil Engineering, May 1977, University Fellow, 1974-1976.

AREAS OF EXPERTISE

Structural Engineering, Structural Mechanics, Computational and Experimental Fracture Mechanics, Microstructural Simulation of Fatigue and Fracture Mechanisms, Rock Mechanics, Numerical Methods, Engineering Education

PROFESSIONAL EXPERIENCE

June 1969 - June 1971
Grumman Aerospace Corporation. Bethpage, L.I., N.Y.
Rotating traineeship in the following areas: preliminary design on Navy F - 14; loads and dynamic studies, stress analysis, and final design on NASA Space Shuttle proposal. Two in - house technical publications.

July 1971 - June 1973
Peace Corps. Bejuma, Venezuela
County Engineer. Responsible for all technical services to a county of 40,000 people. Directed surveying, design, and construction of farmers' market, tourist hotel, and cemetery. Directed urban planning resource study. Co - directed urban renewal plan and data collection for section of state capital city.

September 1973 - August 1977
University of Colorado/Boulder
Department of Civil, Environmental and Architectural Engineering
Instructor for Courses:
Analytical Mechanics, Theoretical Fluid Mechanics
Teaching Assistant for Courses:
Mechanics of Materials
Materials Testing Laboratory
Research Assistant in Project: Constitutive Relations for Coal

September 1977 - June 1982
Cornell University, Department of Structural Engineering
Assistant Professor

September 1979 - July 1983
Cornell University, Department of Structural Engineering
Manager of Experimental Research

July 1982 - June 1987
Cornell University, Department of Structural Engineering
Associate Professor

August 1983 - August 1984
Lawrence Livermore National Laboratory Livermore, California
Visiting Research Engineer: Rock Fracture Simulation

January 1986 - September, 1986
Cornell University, Computer Aided Design Instructional Facility,
College of Engineering
Director

September 1986 - October, 1990
Cornell University, College of Engineering
Faculty Coordinator for Instructional Computing

July 1987 - Present
Cornell University, School of Civil and Environmental Engineering
Professor

September 1987 - April 1992
Cornell University, Program of Computer Graphics
Associate Director

September 1988 - Present
Fracture Analysis Consultants, Inc.
President

October 1990 - October 1994
Cornell University
Director, NSF-Synthesis National Engineering Education Coalition

July 1993 - Present
Cornell University
Dwight C. Baum Professor of Engineering

October 1994 - October 1995
Cornell University
Associate Director, NSF-Synthesis National Engineering Education Coalition

December 1997 –August 2005
Cornell Center for Theory and Simulation in Science and Engineering
Associate Director
Coordinator, Computational Materials Institute

July 1998 – December 1999
Cornell University
Coordinator, Infrastructure Group, School of Civil and Environmental Engineering

November 2002-Present
Cornell University
Member, Graduate Fields of Mechanical and Aerospace Engineering